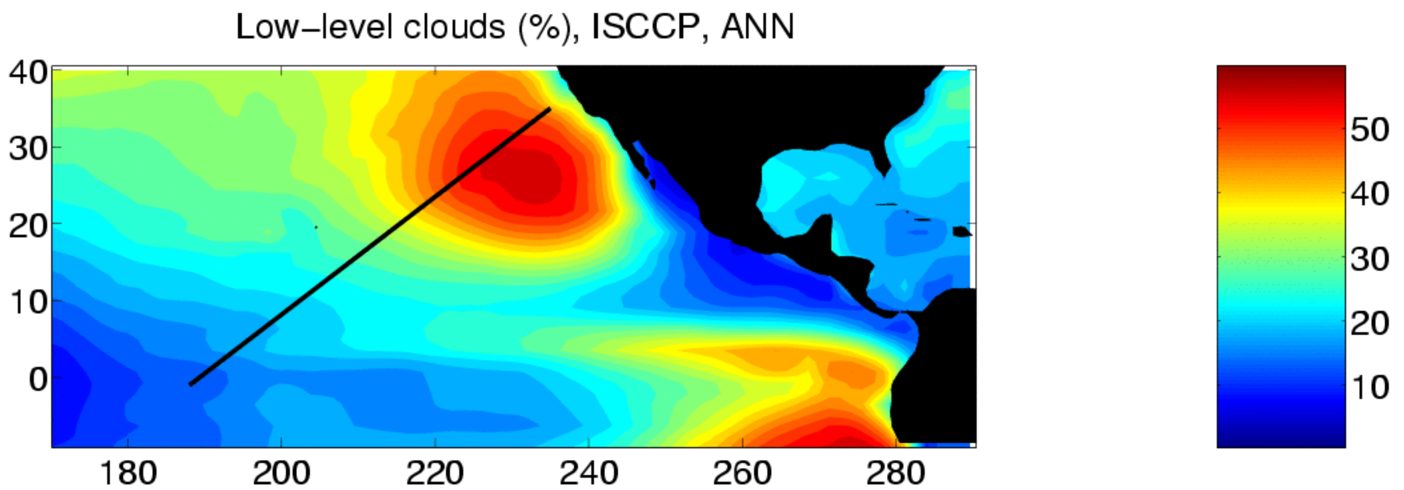
Sc-Cu transition CPT

Goal: Improve the representation of the cloudy boundary layer in NCEP GFS and CAM5 with a focus on the subtropical stratocumulus to cumulus (Sc-Cu) transition



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(with additional internal JPL and DOE funds)

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GFS/CFS motivations for CPT

Enhance interactions with climate science community

- Operational GFS/CFS struggled with insufficient subtropical Sc; in 2010 NCEP introduced new shallow Cu and PBL schemes to operational GFS (Han&Pan 2011) to address this.
- GFS/CFS needs to update its suite of climate bias metrics and use them more rigorously for model evaluation.
- Moist physical parameterization suite could be better tested and improved with controlled GCSS-style single-column tests.
- New parameterization approaches (EDMF turbulence, dual-MF shallow Cu, pdf cloud fraction) could improve GFS/CFS.
- Better GFS/CFS reanalyses benefit climate community

CAM motivations for CPT

- CAM5 also includes new turbulence, shallow Cu, aerosol transport and activation, cloud fraction parameterizations, in part to simulate aerosol indirect effects on climate. These have changed the cloud climatology & feedbacks.
- Interaction of aerosol and subtropical PBL cloud in CAM5 is inadequately understood, and transport of aerosols and cloud droplet concentration are not optimally handled. CAM5 microphysics is sensitive to model timestep
- GFS improves on some features of CAM5 climatology, e. g. convective precipitation and SLP distribution.

CPT Current Main Tasks

a) Better coupled/uncoupled climate diagnostics for GFS (UCLA, NCEP, NCAR)

b) GCSS Sc/Cu cases with NCAR and NCEP SCMs, and LES (UW, NCAR, NCEP, JPL)

c) Development/testing of PDF cloud schemes in NCAR (LLNL, NCAR)

d) Development/testing of EDMF approach in NCAR, NCEP (JPL, NCAR, UW, NCEP)

$$\overline{w'\varphi'} = -k\frac{\partial\overline{\varphi}}{\partial z} + M(\varphi_u - \overline{\varphi})$$

Siebesma & Teixeira, 2000

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a) Better coupled/uncoupled climate diagnostics for GFS
   (UCLA, NCEP, NCAR) – using CAM AMWG diagnostic pkg

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Siebesma & Teixeira, 2000

Comparison of NCAR CESM1 and NCEP GFS

Model	NCAR CESM1	NCEP GFS
Atmosphere	CAM5 (2x2.5, L30)	GFS (T126 L64)
Boundary Layer Turbulence	Bretherton-Park (09) UW Moist Turbulence	Han and Pan (11)
Shallow Convection	Park-Bretherton (09) UW Shallow Convection	Han and Pan (11)
Deep Convection	Zhang-McFarlane Neale et al.(08) Richter-Rasch (08)	Han and Pan (11)
Cloud Macrophysics	Park-Bretherton-Rasch (10) UW Cloud Macrophysics	Zhao and Carr (97)
Stratiform Microphysics	Morrison and Gettelman (08) *Double Moment*	Zhao and Carr (97)
Radiation / Optics	RRTMG Iacono et al.(08) / Mitchell (08)	RRTM
Aerosols	Modal Aerosol Model (MAM) Liu & Ghan (2009)	Climatology
Dynamics	Finite Volume	Spectral
Ocean	POP2.2	MOM4
Land	CLM4	NOAH
Sea Ice	CICE	MOM4

Adapting CESM AMWG diagnostics package to GFS

Xiao (UCLA), Park (NCAR), Sun (NCEP)

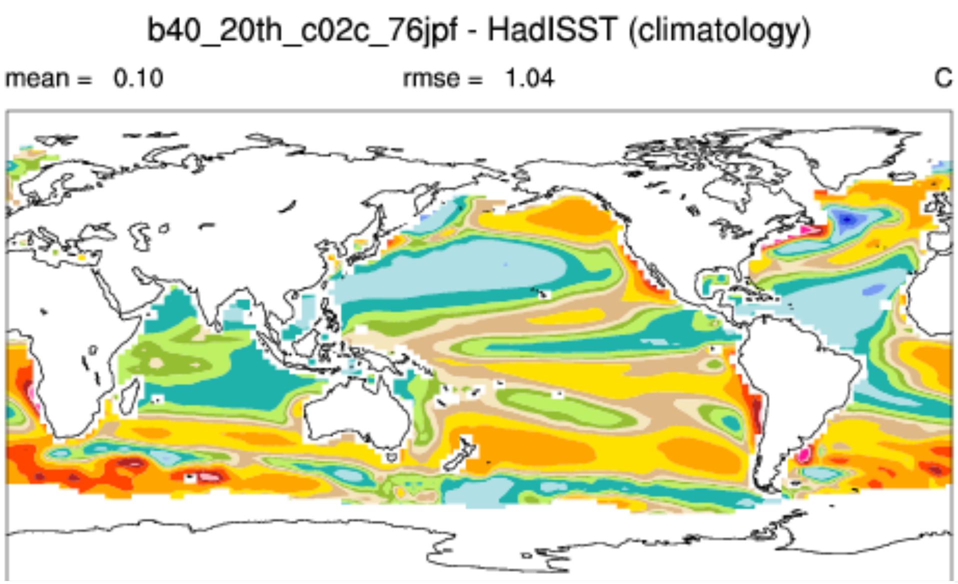
Challenges:

- GFS does not write out all necessary variables (e. g. separate liquid and ice water path)
- GFS nontrivial to run with climatological SSTs, so coupled only

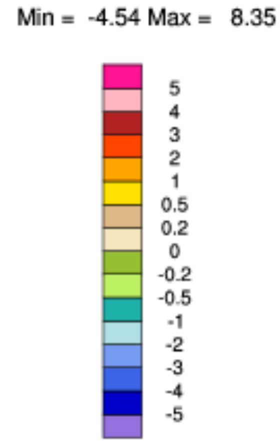
Benefits:

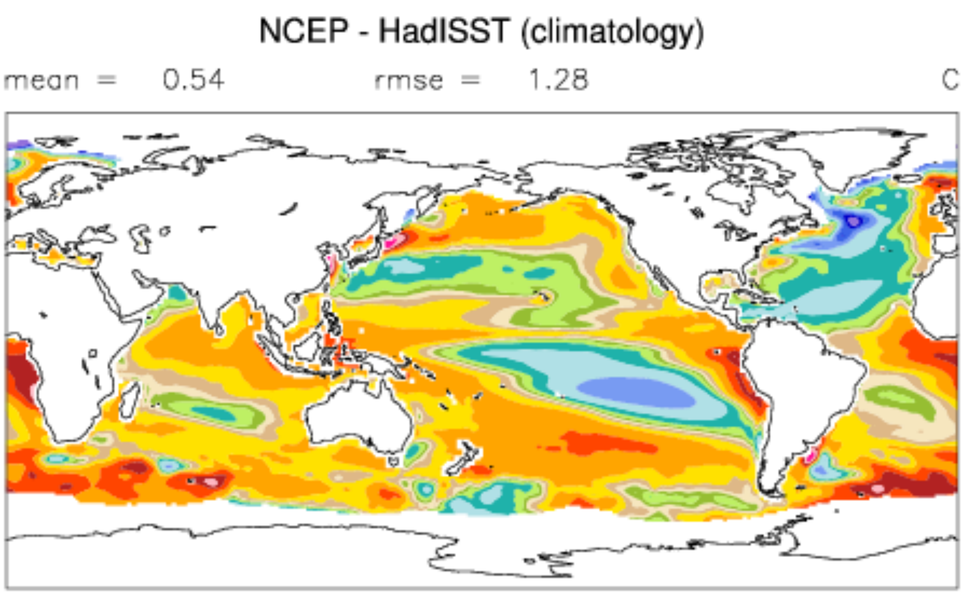
- Results are illuminating and compare with widely-accepted observational metrics of climate model performance.

Sea Surface Temperature Bias



ESM1





Coupled GFS, yr 1-7 (current operational) …larger warm bias, overall worse RMSE

7-year C-GFS vs. 100 yr CESM1 climo: AMWG metrics

cor coef: Space-Time	cam3_5_fv1.9x2.5	b40_20th_c02c_76jpf	NCEP
	ANN	ANN	ANN
Sea Level Pressure (ERA40)	0.949	0.959	0.962
SW Cloud Forcing (CERES2)	0.707	0.714	0.413
LW Cloud Forcing (CERES2)	0.820	0.769	0.792
Land Rainfall (30N-30S, GPCP)	0.785	0.811	0.766
Ocean Rainfall (30N-30S, GPCP)	0.802	0.757	0.748
Land 2-m Temperature (Willmott)	0.876	0.876	0.913
Pacific Surface Stress (5N-5S,ERS)	0.872	0.797	0.856
Zonal Wind (300mb, ERA40)	0.967	0.960	0.940
Relative Humidity (ERA40)	0.900	0.874	0.900
Temperature (ERA40)	0.912	0.932	0.208

C-GFS better than CESM1 for

Pac surface stress, land surface temperature, 3D RH field,

but much worse for

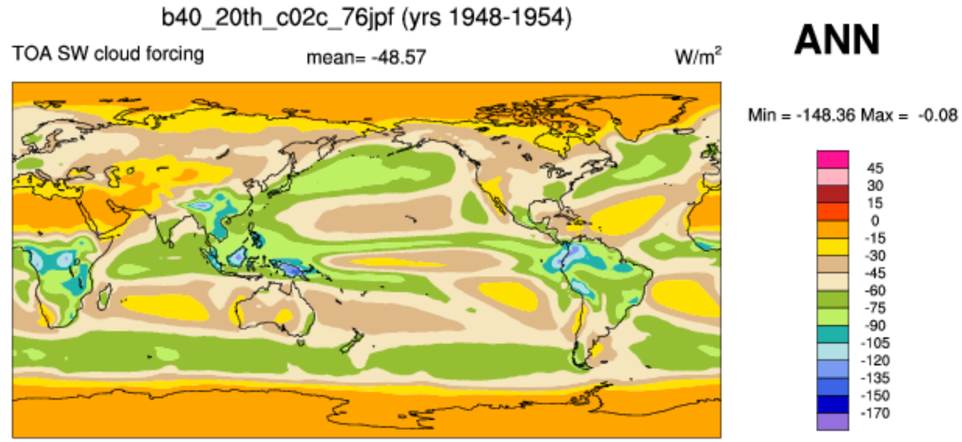
shortwave cloud forcing and land rainfall

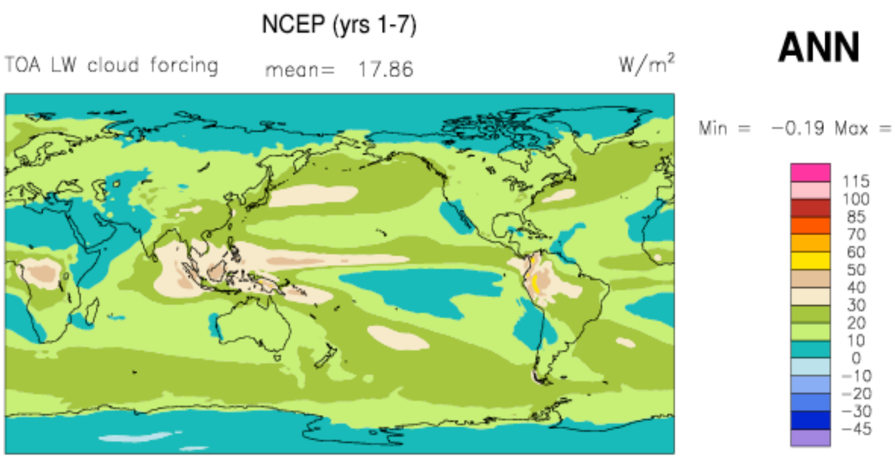
GFS problem area 1

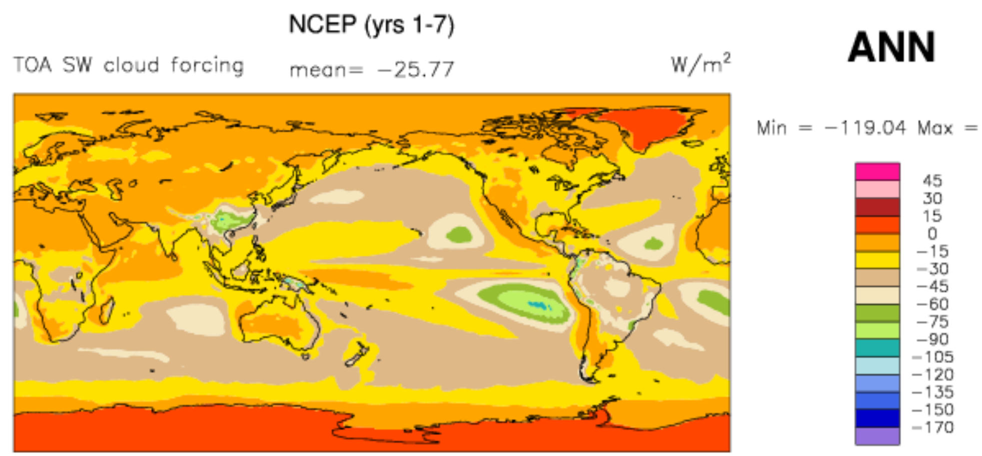
Big low bias in GFS cloud radiative forcing

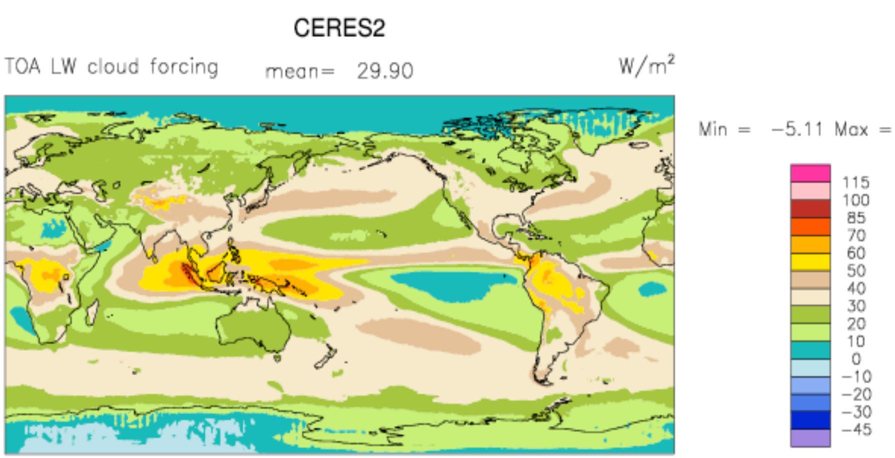
SW:45% = 20 W m^{-2}

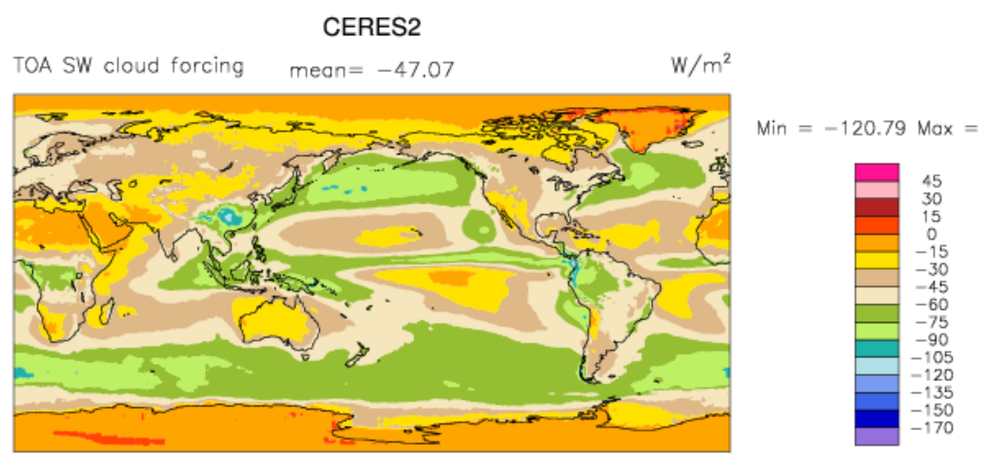
LW: 40% = -12 W m^{-2}







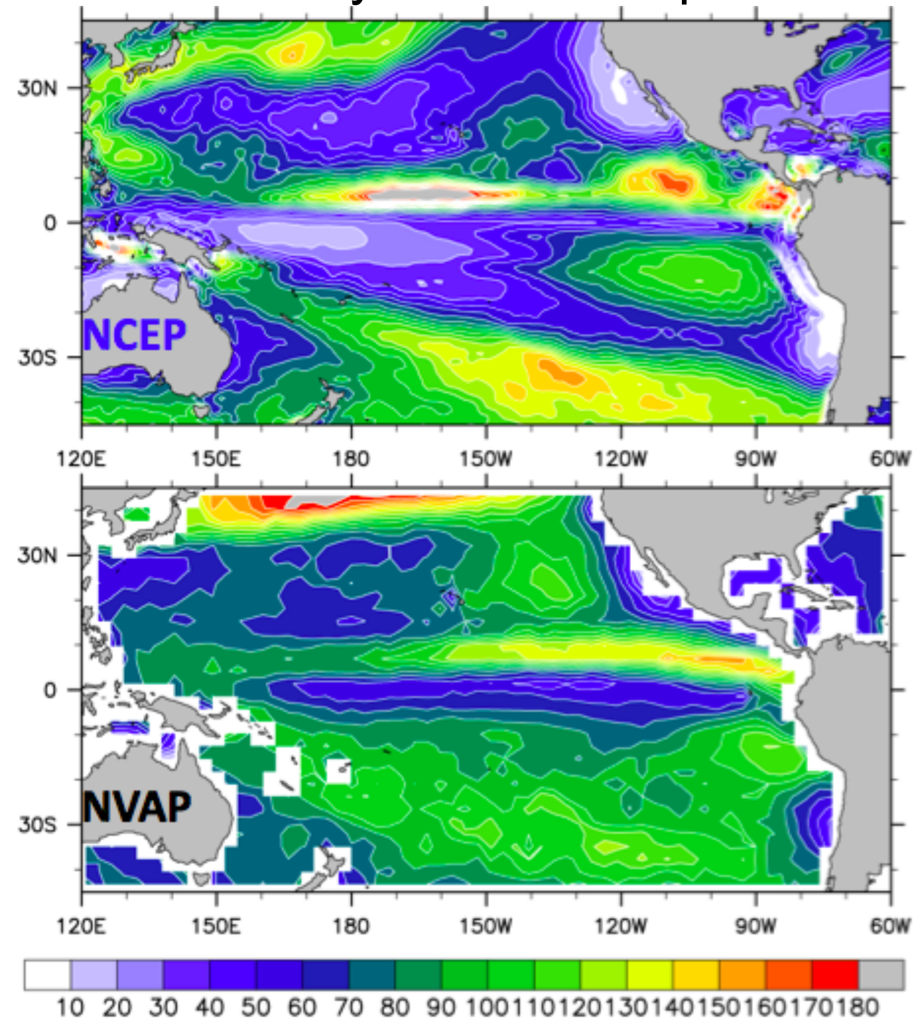




GFS cloud forcing bias, cont.

- Lack of CRF causes C-GFS to absorb 10 W m^{-2} net TOA radiation➔ SST drifts warm.
- There seems to be enough cloud liquid: is cloud liquid or ice particle size used for radiation too large?
- Lack of documentation makes tracing such issues harder.

July cloud water path



GFS problem area 2

GFS atmosphere persistently loses 4-5 W m^{-2} (net TOA flux out is less than surface flux in), compared to 0.006 W m^{-2} in CAM5.

We still don't know why, due to lack of more process-specific diagnostics. Is this also an issue for older GFS/CFS versions? Glenn White of NCEP has agreed to help us look into this.

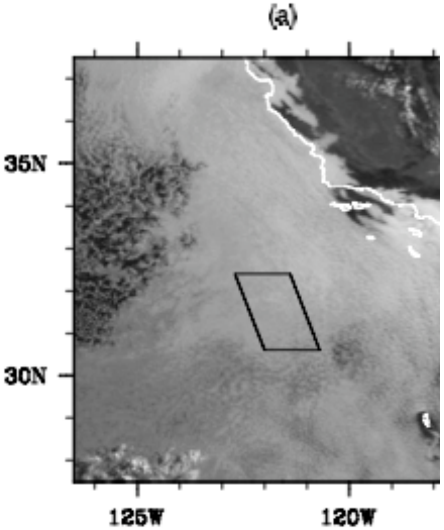
This bias partly compensates energetically for too little cloud, as it initally sucks up half the TOA net incoming radiation.

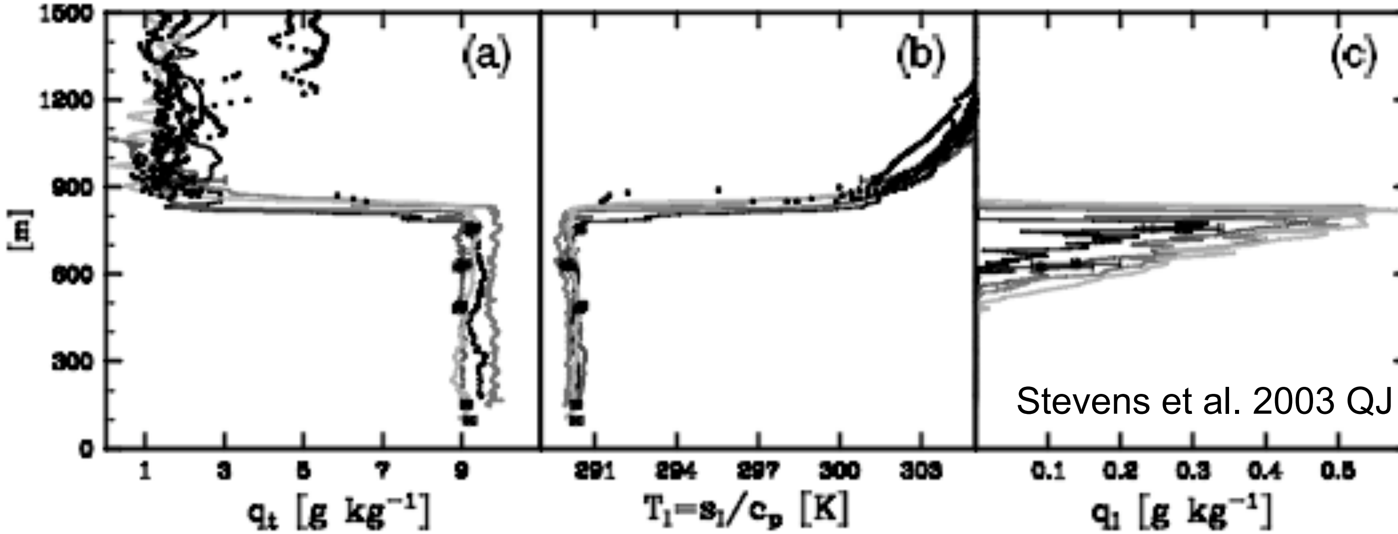
Single-column modeling with GFS

- Single-column GFS existed (pre-2010 physics) but not run outside NCEP, nor on intercomparison cases
- Technical issues:
  - Lack of GFS documentation or useful commenting
  - Code inflexible to changes in forcings, physics, outputs
  - Default outputs inadequate to diagnose parameterizations
- With major effort, SC-GFS runs at UW with new physics and has been adapted to three GCSS cases (Sc, shallow Cu, Sc-Cu transition) for which LES and some observational comparisons exist.
- Results show pathologies and strengths, and suggest some simple model improvements that we are beginning to test.

DYCOMS RF01 nocturnal Sc layer

(Stevens et al 2005; Zhu et al. 2005)

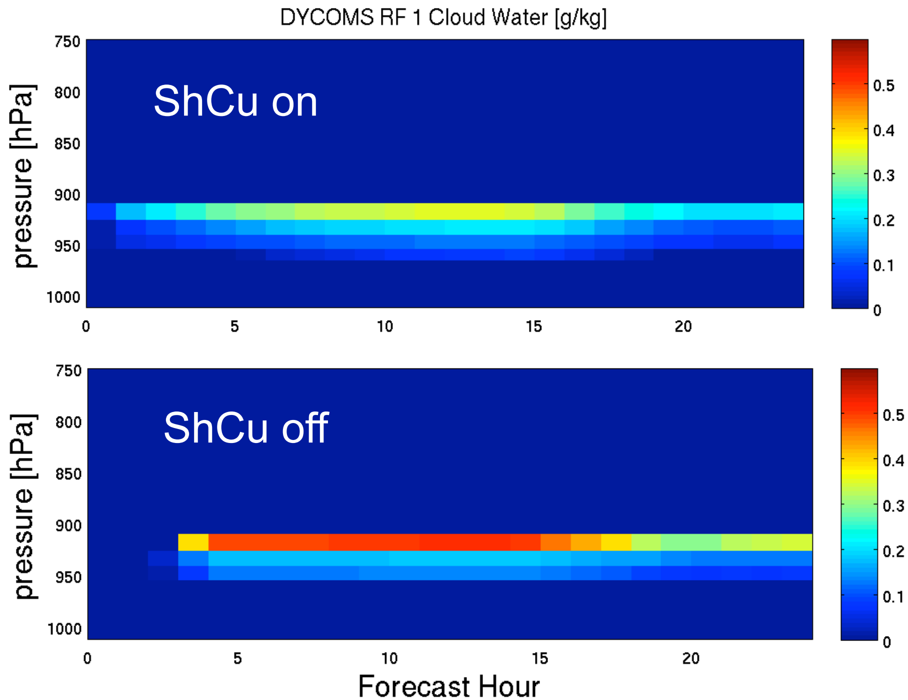


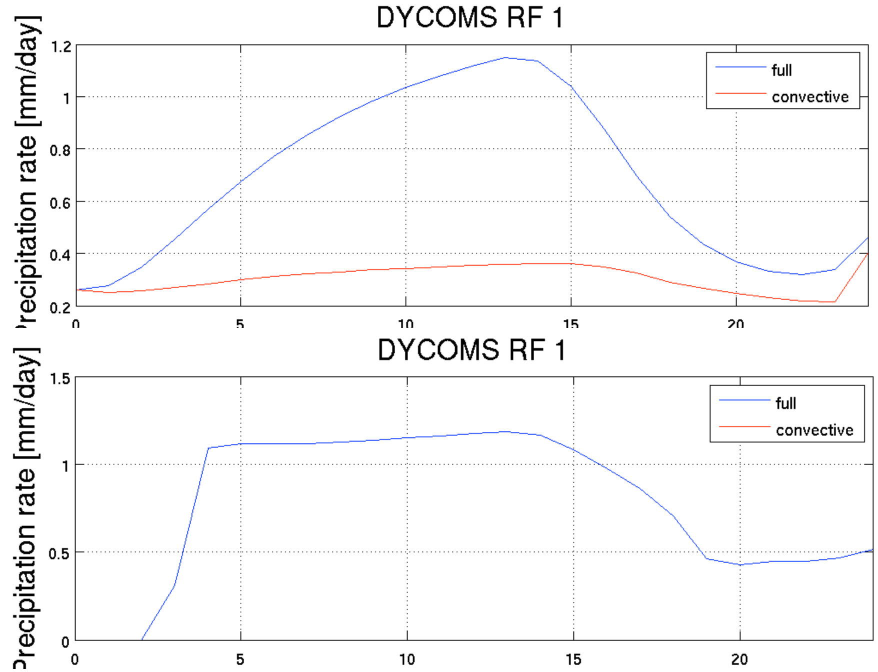


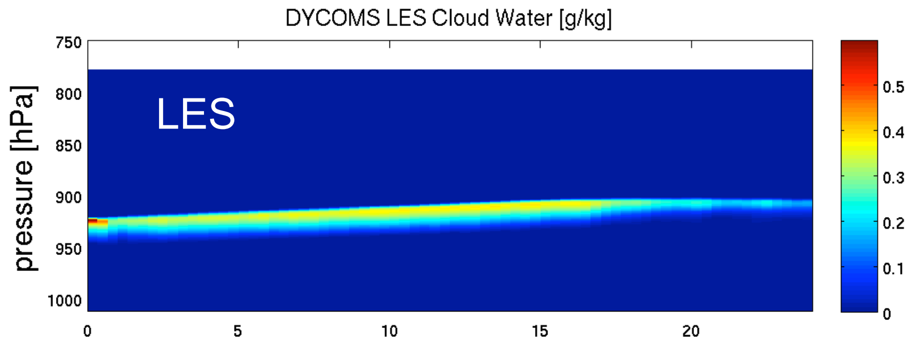
Key features:

- Well mixed radiatively-driven boundary layer; no cumulus
- Nonprecipitating, N_d = 150 cm^{-3}, LWP ~ 60 g m^{-2}
- Deepens slowly due to entrainment
- 24-hour nocturnal LES and SCM simulations

DYCOMS Results: Shallow Cu param overactive, overdrizzles …but without it, Sc thickens too much





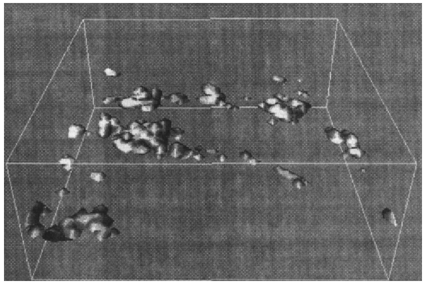


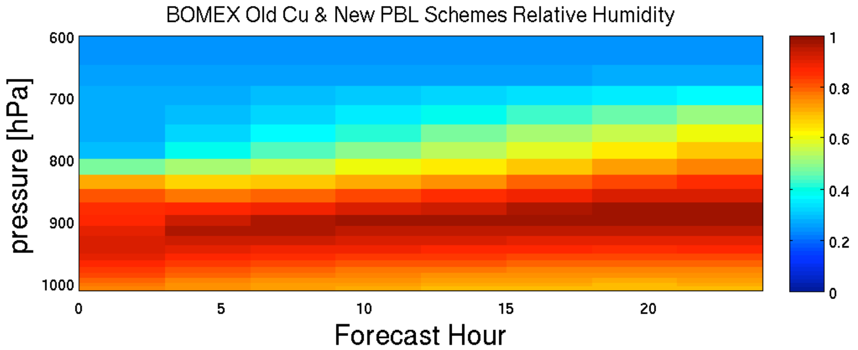
LES precip ~ 0

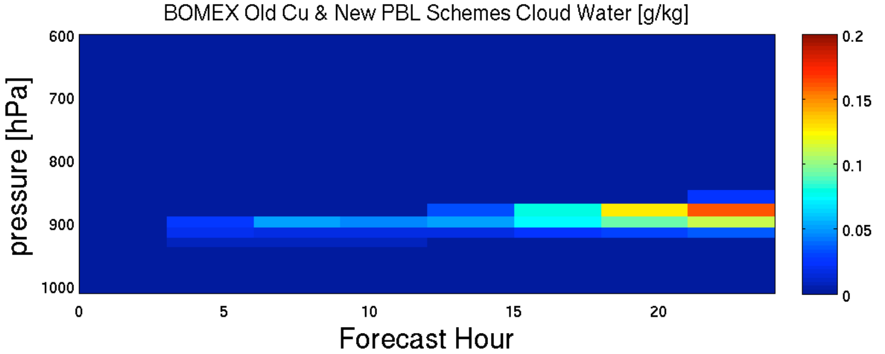
1. Add a Cu-updraft-like component to PBL scheme
2. Turn Cu off unless it penetrates sufficiently above PBL

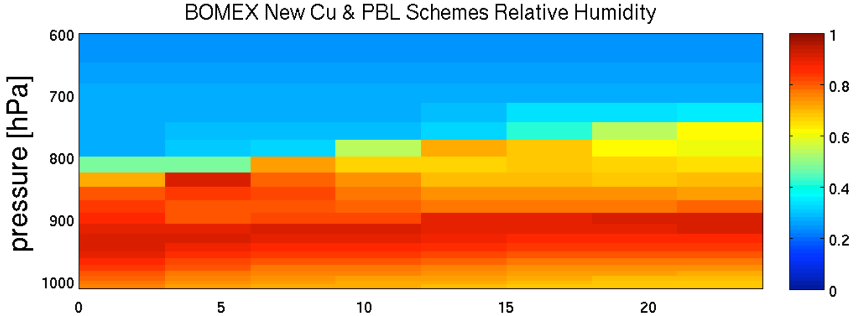
BOMEX nonprecipitating trade Cu case

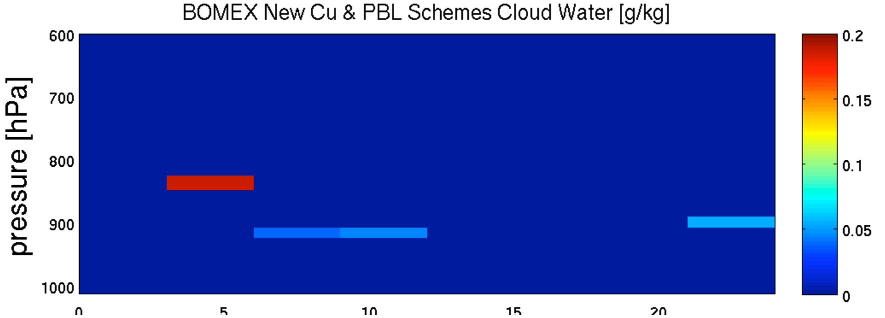
Siebesma et al. 2003

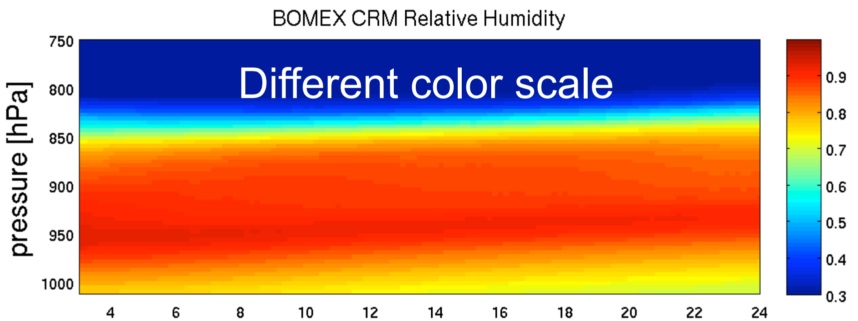


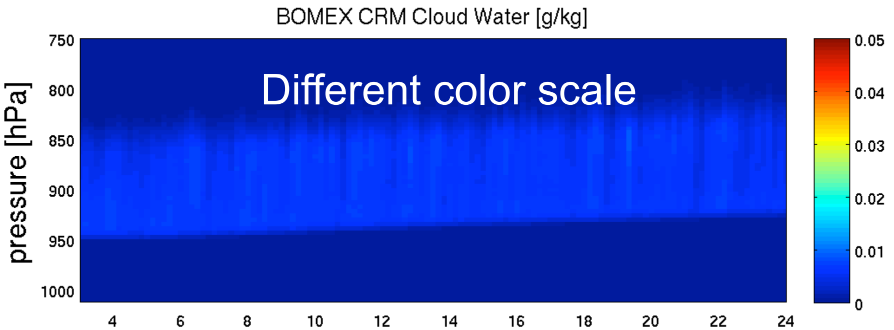






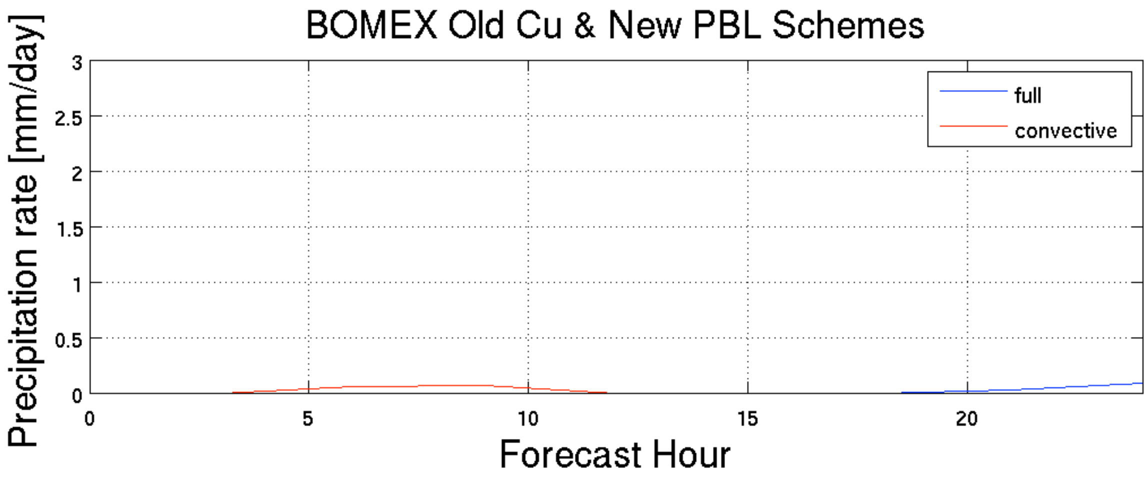


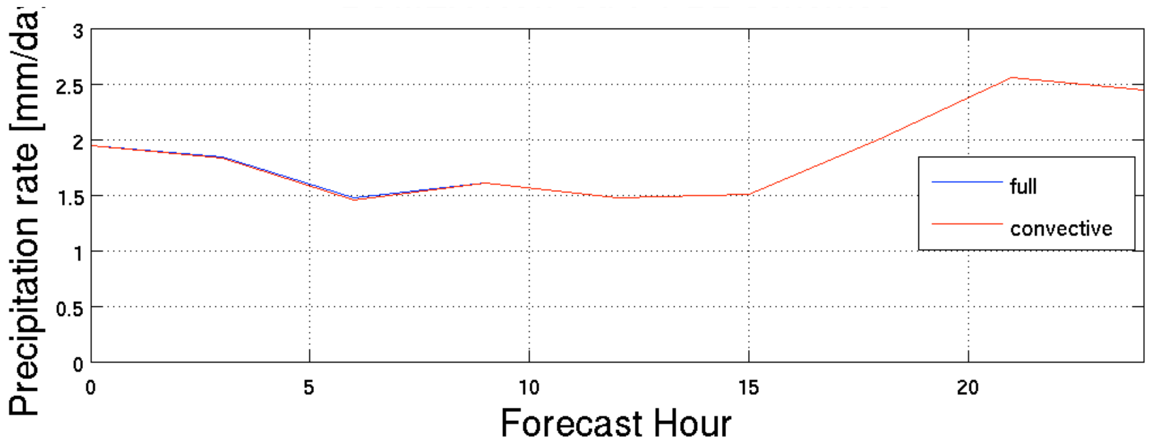




BOMEX Result 1: Cu cloud cover problem for both ShCu schemes

BOMEX, cont.





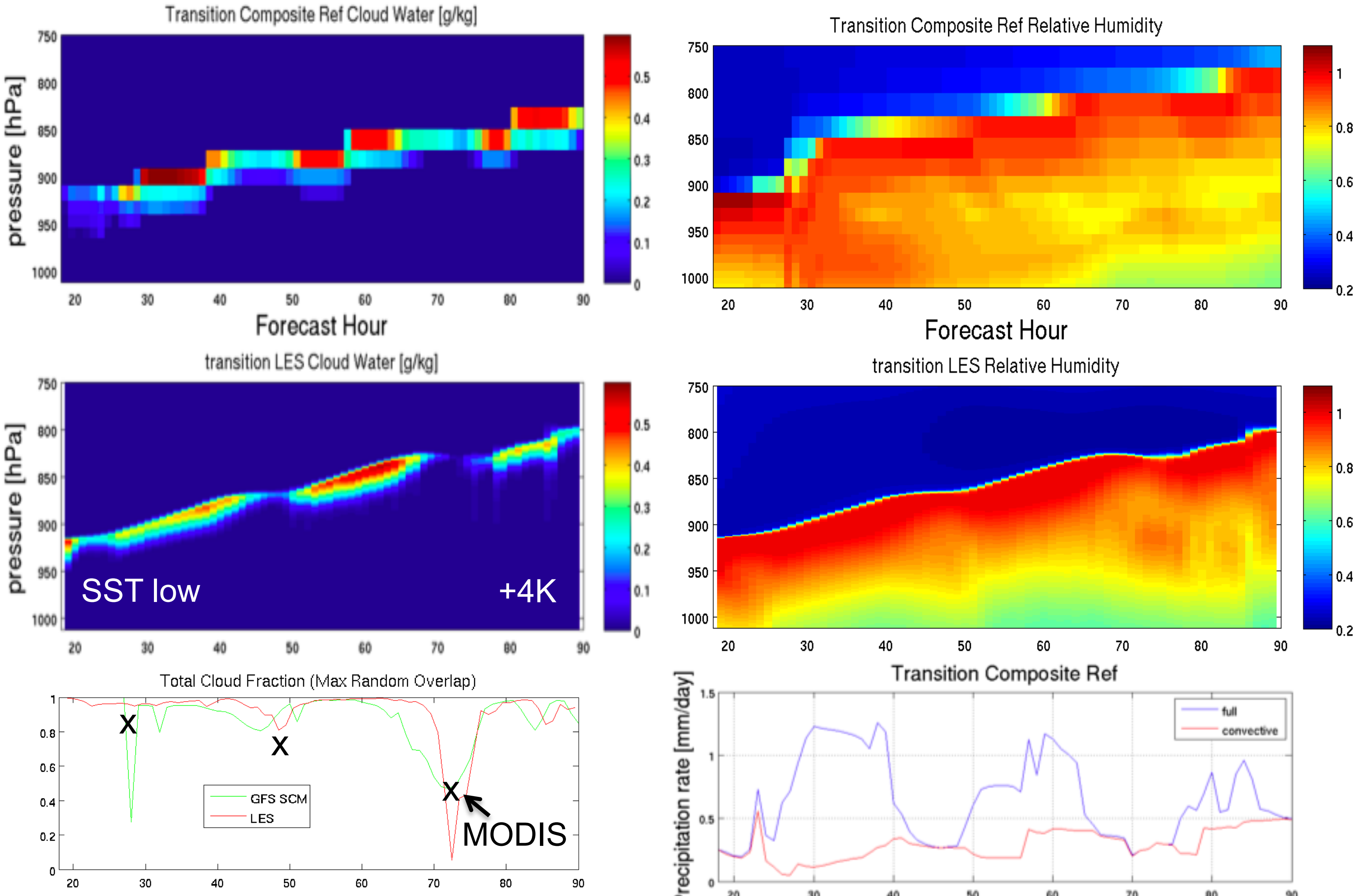
LES and obs: ~0

BOMEX Result 2: Too much rain from new shallow Cu scheme

Possible fix: Raise lateral entrainment, decrease precip efficiency

GCSS composite JJA Sc-Cu transition case

Sandu et al. 2011



Result: SC-GFS does a nice job except for over-raining

Summary

1. CPT implemented new global climate diagnostics for CGFS:
- Many fields as good or better than CESM1 climate model
- Cloud radiative forcing much too weak, biasing climate warm
- An apparent energy leak partly compensates this bias
2. GCSS single-column cases test GFS physics
- Shallow Cu overactive in Sc-topped mixed layers
- Shallow Cu precipitate too much
- Simulated Sc-Cu transition is still surprisingly good
3. Next year: try to fix issues we've found!